Monochromatic Phonon Source

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Principal Investigator(s): Richard Robinson
User(s): Stephanie Dodson, Mahmut Aksit

Affiliation(s): Materials Science and Engineering Department, Cornell University
Primary Research Funding: Startup account
Contact: rdr82@cornell.edu, sld84@cornell.edu, ma573@cornell.edu

Abstract:
We are developing a process for producing a monochromatic phonon source using superconducting tunnel junctions as both generator and detector. Phonon propagation has been used to test the thermophysical properties of material. Superconducting tunnel junctions have been used for phonon spectroscopy. We intend to create a monochromatic phonon source using superconducting tunnel junctions in order to determine the thermophysical properties of nanomaterials.

Introduction to Research:
Superconducting tunnel junctions have been used for phonon spectroscopy. A superconducting tunnel junction consists of two superconducting metal films to act as electrodes with a thin (~ 2 nm) layer of insulator (metal oxide) in between [1]. When a bias voltage, $V$, is applied to the base electrode of an STJ, the energy of the states is higher by a factor $eV$ than the top electrode. Cooper pairs are broken and single electrons tunnel through the oxide layer to leave one excited quasiparticle on each side of the barrier. After tunneling, the quasiparticle will relax down to the energy that is just above the energy gap. This causes phonons of energy range $0$ to $eV-2\Delta$ to be emitted. The quasiparticle will then recombine with another quasiparticle to reform a Cooper pair and emit recombination phonons of energy $2\Delta$. If a modulation $dV$ is applied over the bias voltage then a phase sensitive detector can filter out all but the modulation frequency in order to detect only phonons with energies within $edV$ of $eV-2\Delta$ [2].

Niobium is a superconductor with a high critical temperature of 9.2K. The purity of Niobium is important to its superconductivity. The greater the purity the higher the critical temperature [3].

In our study, we will be testing the phonon propagation through nanomaterials in order to gain insight into the materials’ thermoelectric properties. The device will use superconducting tunnel junctions to act as both the phonon generator and bolometer.

The first step is to determine how/if superconducting niobium can be produced reliably. To do this we will pattern Niobium into strips and test for superconductivity. The second step is to create superconducting tunnel junctions. This requires two layers of superconducting niobium with an oxide layer in between. The native oxide on niobium is unsuitable for our purposes. Aluminum oxide is preferred due to its controllability. Several geometries are viable, our proposed geometry is shown in Figure 1.

Figure 1: L-Edit drawings of proposed superconducting tunnel junction geometry. (a) First layer of niobium to be laid down. (b) Second layer of niobium to be laid down after and oxide layer has been deposited. (c) The device after the two layers of niobium and the oxide layer have been deposited. (d) The device after deposition of gold probe pads. (e) A 2 inch wafer patterned with four quadrants of linewidths used in the device: 2 µm, 4 µm, 6 µm, 8 µm. (f) A view of packing of the devices.
Then we will test the phonon propagation through a material. We will fabricate a superconducting tunnel junction on each side of a bulk crystalline material, one to act as a phonon generator and one to act as a detector. The final goal is to test phonon propagation through nanomaterials. We will begin by fabricating a device consisting of two superconducting tunnel junctions, a phonon generator and a bolometer. Then we will use known techniques to grow or deposit a nanowire across the electrodes of the device.

**Summary of Research:**

Niobium has been deposited using sputter deposition and patterned using standard lift-off techniques. The pattern is that shown in Figure 1a. We used the CVC Magnetron Sputter Deposition system to deposit a layer of niobium approximately 100 nm thick. We used contact photolithography involving 500 nm of LOR5A and PRS1813 STR photoresists. These niobium strips will be tested for resistance/resistivity and superconductivity in a cryostat. The pattern will be imaged using a scanning electron microscope to get more detailed view of the edges of the pattern. The scanning electron microscope can also be used to accurately determine the thickness of the niobium and so determine the deposition rate of the sputter deposition chamber for our parameters. Our next step will be to fabricate complete superconducting tunnel junctions.

First we will lay down all of the layers of the device in the sputter chamber without breaking vacuum and pattern them using etch processing. We will then test them for evidence of quantum mechanical tunneling.

**References:**

